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㉙ Phase shifting masks and methods of manufacture.

㉚ A phase shifting mask comprises a transparent region (20) which is transparent to exposure light and a light shielding region (10) for shielding the exposure light. The transparent region (20) has a light transmitting segment (12) for directly transmitting the exposure light therethrough and a phase shifting segment (11; 11a, 11b) for transmitting the exposure light therethrough with a phase difference from the light passed through the transmitting segment (12). In this structure, the light shielding region (10) is formed adjacent at least the phase shifting segment (11; 11a 11b) or the light transmitting segment (12), and the phase shifting segment and the light transmitting segment are formed adjacent each other.

A method of manufacturing such a phase shifting mask comprises the steps of : forming a light shielding layer on a substrate ; forming a photoresist on the light shielding layer ; patterning the photoresist to form a resist pattern ; providing an opening in the light shielding layer by the use of the resist pattern as a mask, thereby forming a light shielding pattern ; etching the substrate anisotropically to form a phase shifting segment (11, 11a, 11b) ; side etching the light shielding pattern to form a light shielding region (10) ; and removing the resist pattern.

FIG. 4(a)

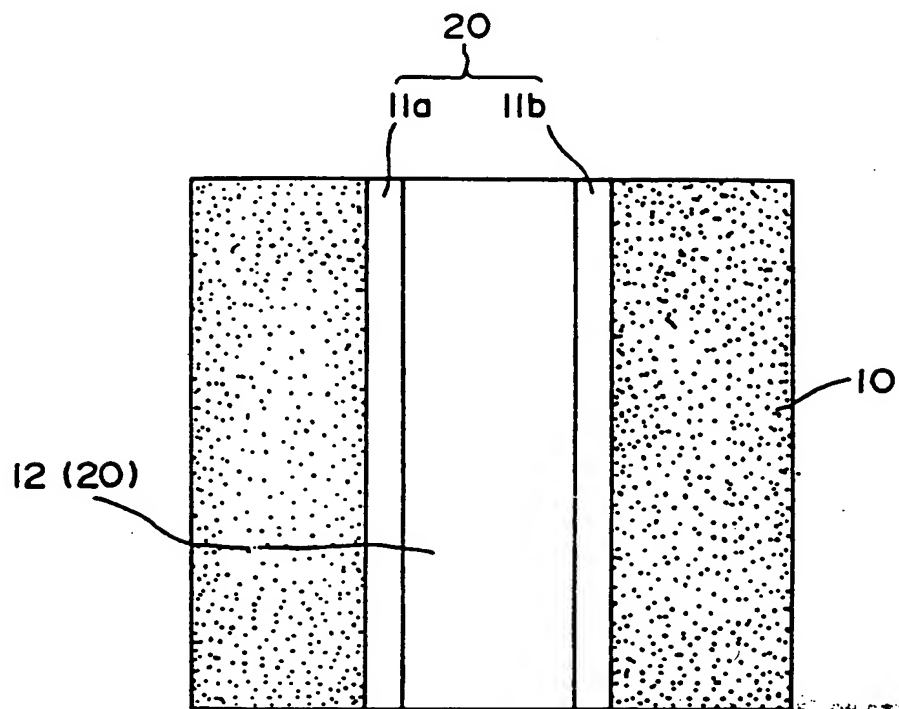
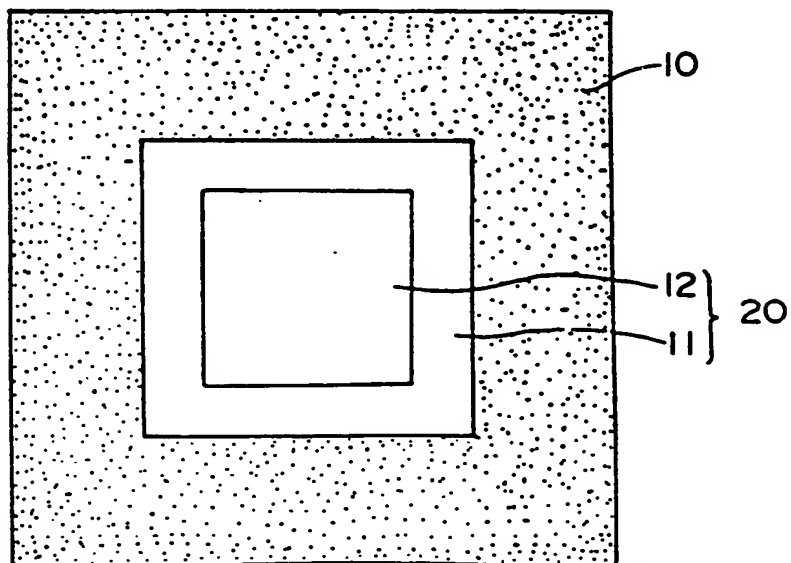


FIG. 4(b)



# PHASE SHIFTING MASKS AND METHODS OF MANUFACTURE

This invention relates to phase shifting masks and to methods of manufacturing such masks, which can be used in the formation of a variety of patterns, such as resist patterns in the process of manufacturing semiconductor devices.

In semiconductor and similar devices, the processing dimensions tend to become increasingly smaller. In the technology of photolithography employed for manufacture of such miniaturised semiconductor devices, there is known, as a means for further enhancing the resolution, a phase shifting technique which causes a phase difference in the light transmitted through a mask and thereby improves the light intensity profile.

This phase shifting method is disclosed, for example, in Japanese Patent Laid-open No. Sho 58 (1983)-173744; in Marc D. Levenson et al., "Improving Resolution in Photolithography with a Phase Shifting Mask", IEEE Transactions on Electron Devices, Vol. ED-29, No. 12, December 1982, pp. 1828 - 1836; and in Marc D. Levenson et al., "The Phase Shifting Mask II; Imaging Simulations and Submicrometer Resist Exposures", Transactions on Electron Devices, Vol. ED-31, No. 6, June 1984, pp. 753 - 763.

The previously-proposed phase shifting method will now be described with reference to Figures 1(a) and 1(b) of the accompanying drawings. In an exemplary case of forming a line-and-space pattern, as shown in Figure 1(a), a light shielding region 10 is formed by the use of a light shielding material such as chromium on a transparent substrate 1 of quartz or the like, and an arrangement of repeated line-and-space patterns is formed to produce an exposure mask. The intensity distribution of the light transmitted through such an exposure mask is represented by a curve A1 in Figure 1(a), wherein the intensity is zero at the light shielding regions 10 while the light is transmitted through the other regions (light transmitting segments 12a, 12b) to provide constant light intensity levels. Viewing one light transmitting segment 12a as an example, the intensity of the light transmitted therethrough and irradiated on a work member to be exposed is distributed as represented by a curve A2 in Figure 1(a), wherein hill-like maxima have flatter regions on either side due to the diffraction of the light. The light passing through the light transmitting segment 12b is represented by a one-dot chained line which is similar to, but dimensionally displaced from, the curve A2. When the light patterns provided by means of the individual transmitting segments 12a, 12b are combined, the light intensity distribution loses its sharpness as indicated by a curve A3, consequently blurring the image due to diffraction of the light, and hence failing to provide a sharp exposure. In contrast therewith, if phase shifting films are pro-

vided on the light transmitting segments of the repeated patterns alternately as shown in Figure 1(b), any blur of the image resulting from diffraction of the light is eliminated by inversion of the phase resulting in a sharp image and thereby improving the resolution and the focusing performance. More particularly, when a phase shifting film 11a is formed on the light transmitting segment 12a as shown in Figure 1(b) in such a manner as to cause a phase shift of 180° for example, the light passed through the phase shifting film 11a is inverted, as represented by a curve B1. The light obtained through the adjacent light transmitting segment 12a does not pass through a phase shifting film so that there is no such phase inversion. Therefore, on the work member to be exposed, the mutually phase-inverted light beams cancel each other at a position B2 corresponding to the flatter regions of the light intensity distribution, whereby the distribution of the light irradiated on the work member is sharpened, as represented by a curve B3 in Figure 1(b).

In the example mentioned above, the greatest advantage is attainable by causing a 180° phase inversion. However, in order to realise such a satisfactory result, it is necessary for the phase shifting film 11a to have a thickness  $d = \lambda/2(n-1)$  (where  $n$  denotes the refractive index of the phase shifting film, and  $\lambda$  denotes the wavelength of the exposure light).

In the process of forming a pattern by exposure, a member used for reduced-size projection may be termed a reticle, and a member for actual-size projection may then be termed a mask; alternatively a member corresponding to an original sheet may be termed a reticle, and a member obtained by duplicating such a reticle may then be termed a mask. In the present description, any one of the masks and reticles classified by such various definitions is generally termed a mask.

Although the above technique utilising the previously-proposed phase shifting mask is very effective for forming an arrangement of repeated patterns such as the line-and-space patterns shown in Figure 1(b), there still exists a problem that such a mask is not readily usable in forming isolated patterns which are not repetitive.

As described above, the phase shifting technique causes a phase difference between the light beams for exposure of mutually adjacent patterns, and utilises the effect that the respectively overlapping light intensities cancel each other. However, since mutually proximate light beams are not present in the case of forming an isolated line or a contact hole, the above phase shifting technique is not directly applicable.

It has therefore been necessary in such cases, as illustrated in Figures 2(a) and 2(b), for a light transmitting region 12 for transmitting exposure light theret-

through without causing any phase shift (phase shift  $0^\circ$ ) to be provided in conformity with a desired pattern to be formed, and a phase shifting region 11 for causing a phase shift of exposure light (such as a phase shift of  $180^\circ$ ) to be provided in the proximity of the light transmitting region 12. (Terasawa et al., Second Draft for Lecture in 49th Applied Physics Society Meeting, Autumn 1988, p. 497, 4a-K-7).

In such an arrangement, a main space is required for constituting a pattern-forming light transmitting segment 12 within a light shielding region 10, and further a sub-space is also required for constituting the phase shifting segments 11. The phase shifting segments 11 are formed along the two sides of and in the proximity of a rectangularly extending light transmitting region 12 which is a main space in the mask of Figure 2(a) for forming an isolated line pattern; alternatively the segments 11 are formed along and in the proximity of four sides of a square light transmitting region 12 in the mask of Figure 2(b) for forming a hole pattern.

In the previously-proposed arrangements of Figures 2(a) and 2(b), the light transmitting segment 12 and the phase shifting segment 11 need to be spaced apart from each other since an insufficient distance therebetween will cause excessive cancellation of the respective light intensities, consequently reducing the transfer pattern. Therefore it is necessary to provide a relatively large area for forming each pattern.

Furthermore, the phase shifting segment 11 needs to have certain dimensions since the effect thereof is diminished in accordance with a dimensional decrease. As a result, there arises another problem in that the pattern of the phase shifting segment 11 is itself transferred. Figure 3 illustrates an exemplary case in which an isolated space 7 is formed by using the mask of Figure 2(a). As shown with some exaggeration in Figure 3, it is unavoidable that patterns 71 derived directly from the phase shifting segments 11 are also formed.

According to a first aspect of the present invention there is provided a phase shifting mask comprising, on a substrate, a transparent region which is transparent to exposure light and a light shielding region for shielding the exposure light, said transparent region having a light transmitting segment for directly transmitting the exposure light therethrough and a phase shifting segment for transmitting the exposure light therethrough with a phase difference from the light transmitted through said light transmitting segment,

characterised in that said light shielding region is formed adjacent at least said phase shifting segment or said light transmitting segment, and said phase shifting segment and said light transmitting segment are formed adjacent each other.

According to a second aspect of the present invention there is provided a method of manufacturing a phase shifting mask, the method comprising the

steps of:

forming a light shielding layer on a substrate;  
forming a photoresist on said light shielding

layer;

5 patterning said photoresist to form a resist pattern;

forming an opening in said light shielding layer by the use of said resist pattern as a mask, thereby forming a light shielding pattern;

10 etching said substrate anisotropically to form a phase shifting segment;

side etching said light shielding pattern to form a light shielding region; and

removing said resist pattern.

15 According to a third aspect of the present invention there is provided a method of manufacturing a phase shifting mask, the method comprising the steps of:

forming a light shielding layer on a substrate;

20 forming a photoresist on said light shielding

layer;

patterning said photoresist to form a resist pattern;

25 forming an opening in said light shielding layer by the use of said resist pattern as a mask, thereby forming a light shielding pattern;

30 etching said substrate anisotropically to form a phase shifting segment;

removing said resist pattern; and

35 etching said light shielding pattern isotropically to form a light shielding region.

According to a fourth aspect of the present invention there is provided a method of manufacturing a phase shifting mask, the method comprising the steps of:

forming a light shielding layer on a substrate;

forming a photoresist on said light shielding

layer;

40 patterning said photoresist to form a resist pattern;

forming an opening in said light shielding layer by the use of said resist pattern as a mask, thereby forming a light shielding pattern;

45 side etching said light shielding pattern to form a light shielding region;

depositing a phase shifting material in said opening by the use of said resist pattern as a mask; and

50 removing said resist pattern together with phase shifting material thereon to form a phase shifting segment in said opening.

According to a fifth aspect of the present invention there is provided a method of manufacturing a phase shifting mask, the method comprising the steps of:

forming a light shielding layer on a substrate;

forming a photoresist on said light shielding

layer;

patterning said photoresist to form a first resist pattern ;

forming an opening in said light shielding layer by the use of said first resist pattern as a mask, thereby forming a light shielding pattern ;

removing said first resist pattern ;

forming a photoresist on said light shielding pattern and said opening ;

removing said photoresist partially from said opening thereby forming a second resist pattern ;

anisotropically etching said substrate in a partial area of said opening thereby forming a phase shifting region ; and

removing said second resist pattern.

According to a sixth aspect of the present invention there is provided a method of manufacturing a phase shifting mask, the method comprising the steps of :

forming a light shielding layer on a substrate ;

forming a photoresist on said light shielding layer ;

patterning said photoresist to form a first resist pattern ;

forming an opening in said light shielding layer by the use of said first resist pattern as a mask, thereby forming a light shielding pattern ;

removing said first resist pattern ;

forming a layer of a phase shifting material on said light shielding pattern and said opening ;

forming a photoresist on said layer of the phase shifting material ;

removing said photoresist in such a manner as to leave a second opening which is positioned over and is narrower than the first-mentioned opening, thereby forming a second resist pattern ;

anisotropically etching said layer of the phase shifting material by the use of said second resist pattern as a mask, thereby forming a phase shifting region ; and

removing said second resist pattern.

According to a seventh aspect of the present invention there is provided a method of manufacturing a phase shifting mask, the method comprising the steps of :

forming a light shielding layer on a substrate ;

forming a photoresist on said light shielding layer ;

patterning said photoresist to form a first resist pattern ;

forming an opening in said light shielding layer by the use of said first resist pattern as a mask, thereby forming a light shielding pattern ;

removing said first resist pattern ;

forming a photoresist on said light shielding pattern and said opening ;

removing said photoresist partially from said opening thereby forming a second resist pattern ;

depositing a phase shifting material in said

opening partially by the use of said second resist pattern as a mask ; and

removing said second resist pattern together with said phase shifting material thereon to leave a phase shifting segment in a partial area of said opening.

Embodiments of the present invention described in greater detail hereinafter provide an improved phase shifting mask which can have a reduced pattern-forming area thereby decreasing the space required while preventing transfer of any unrequired pattern of a phase shifting film even when forming an isolated line (space) or a hole pattern.

The embodiments of the present invention also provide improved methods of manufacturing a phase shifting mask, which are capable of minimising the number of required steps, particularly by overcoming the necessity of executing a plotting step twice to obtain a mask of a desired structure.

The invention will now be described by way of example with reference to the accompanying drawings, throughout which like parts are referred to by like references, and in which :

Figures 1(a) and 1(b) illustrate the principle of a phase shifting exposure mask ;

Figures 2(a) and 2(b) illustrate exemplary structures of previously-proposed phase shifting masks ;

Figure 3 is a partially sectional perspective view of a work member prepared using the mask of Figure 2(a) ;

Figures 4(a) and 4(b) are plan views illustrating the structures of exemplary phase shifting masks according to embodiments of the present invention ;

Figures 5(a) to 5(c) and Figures 6(a) to 6(c) graphically show light intensity distributions according to embodiments of the present invention ;

Figures 7(a) to 7(f) illustrate sequential steps in manufacture of a first embodiment of the invention, with sectional views of a phase shifting mask during these steps ;

Figures 8(a) to 8(f) similarly illustrate sequential steps for a second embodiment of the invention ; Figures 9(d) to 9(f) similarly illustrate later sequential steps for a third embodiment of the invention, the earlier steps being as shown in Figures 7(a) to 7(c) ;

Figures 10(a) to 10(f) illustrate sequential steps in manufacturing the phase shifting mask of a fourth embodiment of the invention ;

Figures 11(d) to 11(f) illustrate the later steps in manufacturing a phase shifting mask according to a fifth embodiment of the invention, the earlier steps being as shown in Figures 10(a) to 10(c) ; and

Figures 12(f) and 12(g) illustrate the later steps in

manufacturing a phase shifting mask according to a sixth embodiment of the invention, the earlier steps being as shown in Figures 10(a) to 10(e).

As illustrated in Figures 4(a) and 4(b), phase shifting masks embodying the present invention each comprise a transparent region 20 (transparent with respect to exposure light) and a light shielding region 10. The transparent region 20 has a light transmitting segment 12 for directly transmitting the exposure light therethrough, and phase shifting segments 11, 11a, 11b for transmitting the exposure light therethrough with a phase difference from the light transmitted through the light transmitting segment 12. The light shielding region 10 is formed so as to be adjacent at least the phase shifting segments 11, 11a, 11b or the light transmitting segment 12. The light transmitting segment 12 may be composed so as to permit transmission of the exposure light without any phase shift.

In both the examples of Figures 4(a) and 4(b), the light shielding region 10 is positioned adjacent the phase shifting segments 11, 11a, 11b. However, the arrangement may be modified so that the light shielding region 10 is adjacent the light transmitting segment 12. More specifically, in the example of Figure 4(a), two rows of phase shifting segments 11a, 11b are formed adjacent respective sides of a light transmitting segment 12 corresponding to an isolated line (space) pattern, and the phase shifting segments 11a, 11b are positioned adjacent the surrounding light shielding region 10. However, the above arrangement may be modified so that a phase shifting segment of a shape corresponding to a desired pattern may be formed at the centre, and rows of light transmitting segments may be formed on respective sides of the phase shifting segment region, in such a manner that the light transmitting segments and the light shielding region 10 adjoin mutually.

Further, in the example of Figure 4(b), a phase shifting segment 11 is formed adjacent a light transmitting segment 12 which corresponds to a desired hole pattern, in a manner to surround the four sides of the light transmitting segment 12, and the phase shifting segment 11 adjoins the peripheral light shielding region 10. However, this arrangement may be modified so that a phase shifting segment of a shape corresponding to a desired hole pattern is formed at the centre, while a light transmitting segment is formed in a manner which surrounds the phase shifting segment, and the light transmitting segment and the light shielding segment 10 adjoin mutually.

Regarding the exemplary structures illustrated in Figures 4(a) and 4(b), the same phase shifting effect can be attained even in each of the modifications where the phase shifting segments 11, 11a, 11b are positionally interchanged with the light transmitting segment 12. This will be easily understood from the principle of a phase shifting mask, namely that the phases of mutually proximate light beams cancel

each other thereby enhancing the resolution.

In embodying the present invention, a transparent region 20 on a mask is generally divided into two mutually adjacent segments, and these segments are composed so as to cause a phase difference between exposure light transmitted therethrough. The effect thereby achieved is optimised when the phase difference is 180°.

In the present phase shifting technique, the light transmitted through the periphery of the central area (light transmitting segment 12 in Figures 4(a) and 4(b)) of the transparent region 20 is cancelled by the light transmitted through the outer difference-phase areas (phase shifting segments 11, 11a, 11b in Figures 4(a) and 4(b)), so that the intensity of the former light is rendered lower than the intensity obtained in a different structure where the central area (light transmitting segment 12) alone is present. Therefore, the resultant pattern becomes considerably smaller as compared to the pattern exposed and transferred in the structure where merely the central area (light transmitting segment 12) is present. For this reason, the central area (light transmitting segment 12) is formed to be greater than the size of the desired pattern to be obtained so that it becomes possible to transfer a pattern of the desired size. Also, the resolution of the pattern thus obtained can be enhanced due to the effect of the phase shifting process.

In an exemplary case of transferring a contact hole pattern by the use of the above-described structure, the following effects are attainable. This example represents a case in which there is formed a contact hole of a 0.15- $\mu$ m square by using a KrF excimer laser (light wavelength 248 nm).

According to a previously-proposed exposure mask obtained merely with a pattern of a 0.35- $\mu$ m square transparent region without employment of the phase shifting technique, the light intensity distribution on a wafer or a similar work member to be exposed becomes as graphically shown in Figure 5(a). In the case of using another previously-proposed mask as shown in Figure 2(b) which utilises the phase shifting technique, the light intensity is increased as graphically shown in Figure 5(b). However, since a sub-space (Figure 2(b)) constituting a phase shifting segment 11 alone has a light intensity to a certain degree, its pattern may possibly be transferred as well. In contrast to this, when the mask of Figure 4(b) is employed, the light intensity can be increased solely in the hole area as graphically shown in Figure 5(c).

In Figures 5(a) to 5(c), the light intensities denote the results of calculations, and the values thereof are indicated by equi-intensity curves on the exposure surface. In each diagram, the abscissa and ordinate represent lengths in  $\mu$ m.

As will be apparent from the comparison of the diagrams of Figures 5(a) to 5(c), if the central area (light transmitting segment 12 of Figure 4(b)) of the

transparent region 20 in the present embodiment of Figur 5(c) is formed to be a 0.46- $\mu\text{m}$  square and the peripheral opening is formed to be a 0.70- $\mu\text{m}$  square, then substantially the same light intensity distribution as that of Figure 5(b) can be obtained.

Thus, according to the present phase shifting mask technique, the space can be minimised without inducing transfer of any unrequired pattern, hence ensuring a high resolution.

Each of Figures 6(a) to 6(c) graphically shows the light intensity distribution obtained on an exposed work member such as a wafer by the use of a KrF excimer laser in transferring an isolated line pattern of 0.25  $\mu\text{m}$  in width. In these graphs, the abscissa represents length in  $\mu\text{m}$ , and the ordinate represents an absolute value of the light intensity on the exposed work member with the irradiated light regarded as unity.

Figure 6(a) graphically shows the result obtained relative to a previously-proposed mask without using the phase shifting technique, wherein the light intensity distribution 1a on the exposed work member is curved in conformity with the irradiated light 11a passed through the light transmitting segment of the mask. The maximum light intensity in the distribution 1a on the exposed work member was 0.5299.

Figure 6(b) graphically shows the result obtained by a previously-proposed phase shifting mask according to Figure 2(a). The intensity distribution 1b1 of the pattern exposure light corresponding to the irradiated light 11b1 through the light transmitting segment 12 in Figure 2(a) indicates a major maximum intensity of 0.6640. However, a sub-peak is generated in the intensity distribution 1b2 of the irradiated light 11b2 through the phase shifting segment 11, and its maximum value of 0.2902 is considerable. This signifies that the possibility of transfer of an unrequired pattern is high.

In contrast therewith, the result obtained relative to the embodiment of Figure 4(a) is graphically shown in Figure 6(c), wherein the light intensity distribution 1c1 on the exposed work member corresponding to the irradiated light 11c1 through the light transmitting segment 12 in Figure 4(a) indicates a maximum intensity of 0.6786 which is greater than any of the previous values. It is further apparent that substantially no peak is generated in the phase shifting segments 11a, 11b of Figure 4(a) corresponding to the irradiated light 11c2, hence preventing transfer of any unrequired pattern.

Various methods of manufacturing phase shifting masks, such as those of Figures 4(a) and 4(b), will now be described.

A first embodiment comprises the following steps as illustrated in Figures 7(a) to 7(f). An opening is provided in a light shielding layer to form a light shielding pattern, and then the light shielding pattern is processed by side-etching while being marked with a photo-

resist to form a light shielding region of the phase shifting mask.

Further details of this embodiment will now be described with reference to Figures 7(a) to 7(f). In this embodiment, a film of a material having light shielding properties (for example, chromium or any other material such as a heavy metal or oxide thereof suited to shield exposure light) is formed as a light shielding layer 10' on a substrate 1 (of silicon dioxide or the like) having light transmitting properties; and a photoresist 2' is formed as a film on the light shielding layer 10' by coating or the like thereby to produce a structure as shown in Figure 7(a).

Subsequently an electron beam (EB) plotting step is executed, and the photoresist 2' is patterned thereby to form a resist pattern 2 with a resist opening 21, as illustrated in Figure 7(b).

In the next step, a light shielding pattern 10b with an opening 10a is obtained by the normal technique of photolithography while being masked with the resist pattern 2, as illustrated in Figure 7(c). Since the opening 10a corresponds to the phase shifting segment 12 (see Figure 7(f)) of a final desired structure, both the opening 10a and the resist opening 21 are formed in conformity therewith.

Thus, the resist pattern 2 is obtained by EB-plotting and developing the resist 2'; and the light shielding layer 10' is patterned by etching or the like while being masked with the resist pattern 2. Until this stage, the processing steps are the same as those adopted in manufacture of an ordinary reticle, and therefore known techniques may be employed.

Subsequently in this embodiment, the substrate 1 is etched while being masked directly with the resist pattern 2, whereby a recess 1a is formed in the substrate as illustrated in Figure 7(d). The etching depth d (depth of the recess 1a) is selectively determined as  $d = \lambda/2(n-1)$  where  $\lambda$  denotes the wavelength of light employed for exposure, and n denotes the refractive index of the substrate 1 to the exposure light. The phase shifting effect is maximised when the above condition is satisfied.

Subsequently, the light shielding pattern 10b is side-etched while being masked with the resist pattern 2, whereby a structure as shown in Figure 7(e) is obtained, with a light shielding region 10 in which the light shielding pattern 10b is partially etched on both sides of the recess 1a in the substrate 1. Portions 10c, 10d are removed from the light shielding pattern 10b by the etching in this step.

In the above process, "side etching" signifies etching in a lateral direction (leftward-rightward lateral direction in the drawing) orthogonal to the depth of the light shielding pattern 10b (upward-downward vertical direction in the drawing). Such side etching can be executed with a suitable agent which causes an erosive action on the material of the light shielding pattern 10b. For example, the side etching can be

effected in a wet etching mode with a selected etching liquid which meets the above requirement. Since the side-etched portions 10c, 10d correspond to the light transmitting segments 11a, 11b respectively as illustrated in Figure 7(e), the amount of such etching is determined in conformity with the desired size.

Finally, the resist pattern 2 is removed to produce a phase shifting mask structure as shown in Figure 7(f), which comprises a transparent region 20 with respect to exposure light and a light shielding region 10 for shielding the exposure light, wherein the transparent region 20 has light transmitting segments 11a, 11b for directly transmitting the exposure light therethrough, and the phase shifting segment 12 for transmitting exposure light therethrough with a phase difference from the light passed through the light transmitting segments.

The plan-view constitution of the phase shifting mask may be shaped into a contact hole pattern as shown in Figure 4(b) or a line (space) pattern as shown in Figure 4(a).

According to the method described above, a desired structure can be achieved with only a single plotting step (Figure 7(b)), which step requires the highest precision and the longest time.

In a second embodiment comprising the steps shown in Figures 8(a) to 8(f), a light shielding layer 10' is formed of chromium or the like on a substrate 1 (of quartz, silicon dioxide or the like) having light transmitting properties, as illustrated in Figure 8(a). The thickness of the light shielding layer 10' is selectively determined to be greater than the thickness of a light shielding region 10 which is to be finally obtained. A resist 2' is formed on the light shielding layer 10' by coating or the like to produce the structure shown in Figure 8(a).

Subsequently, a plotting step is executed, and then the resist 2' is exposed and developed to form a resist opening 21, thereby producing a resist pattern 2 as illustrated in Figure 8(b).

Thereafter, the light shielding layer 10' is anisotropically etched while being masked with the resist pattern 2, whereby an opening 10a is formed in the light shielding layer to obtain a structure as shown in Figure 8(c). Since the opening 10a corresponds to the phase shifting segment 12 (see Figure 8(f)) in a desired final structure, both the opening 10a and the resist opening 21 are formed to have proper dimensions conforming therewith.

Subsequently, the substrate 1 is anisotropically etched while being masked with the resist pattern 2, thereby obtaining a structure as shown in Figure 8(d), having a substrate recess 1a. Since this recess 1a serves as the phase shifting segment 12, the depth d thereof in this embodiment is selected so as to be equal to that of the substrate recess 1a in the first embodiment of Figures 7(a) to 7(f), so as to maximise the phase shifting effect.

The resist pattern 2 is then removed in order to attain a state as illustrated in Figure 8(e).

Next, isotropic etching is executed to remove the light shielding layer in the periphery of the recess 1a, thereby producing a structure as shown in Figure 8(f). The isotropic etching may be carried out by any means capable of isotropically etching the light shielding material, and a wet etching means may be employed. As the portions to be removed by such isotropic etching serve as the light transmitting segments 11a, 11b, the required amount of etching is determined in conformity therewith.

By the use of a single plotting step, the phase shifting mask structure of Figure 8(f) can be obtained, comprising a transparent region 20 (transparent with respect to the exposure light) and a light shielding region 10 for shielding such exposure light, wherein the transparent region 20 has light transmitting segments 11a, 11b for directly transmitting the exposure light therethrough, and the phase shifting segment 12 for transmitting the exposure light therethrough with a phase difference from the light passed through the light transmitting segments.

In comparison with the first and second embodiments shown in Figures 7(a) to 7(f) and Figures 8(a) to 8(f) in which segments for causing a phase difference between light rays transmitted therethrough are formed by partially changing the thickness of the substrate 1, a third embodiment shown in Figures 9(d) to 9(f) is arranged so as to form a projection 42 on the substrate 1, the projection 42 being formed from a suitable material having a phase shifting effect, wherein the projection is used as the phase shifting region 12 (see Figure 9(f)).

In manufacture of this embodiment, the same steps as those for the first embodiment are executed in an early stage. More specifically, the steps of Figures 7(a) to 7(c) are initially performed; accordingly a detailed description of these steps will not be given here. After the step of Figure 7(c), first the light shielding pattern 10b is side-etched to obtain a structure as shown in Figure 9(d) with portions 10c, 10d where the light shielding layer has been removed. Thus, in contrast with the first embodiment in which the substrate 1 is etched, such etching is not executed in the third embodiment and side etching is started immediately.

A suitable material having a phase shifting effect, such as silicon dioxide, is then evaporated by means of chemical vapour deposition (CVD) or the like, thereby forming the projection 42 of phase shifting material of a size corresponding to a resist opening 21 in the resist pattern 2, as illustrated in Figure 9(e). Simultaneously therewith, a film 41 of phase shifting material is formed on the resist pattern 2 as well.

With subsequent removal of the resist pattern 2, the film 41 is also removed, consequently providing a phase shifting mask structure as shown in Figure 9(f) which comprises a light shielding region 10 and a

transparent region 20 having a phase shifting segment 12 composed of the phase shifting projection 42 and the light transmitting segments 11a, 11b formed by the side etching step.

In this embodiment also, merely a single plotting step is sufficient, as in the previous embodiments.

A description will now be given of another method of producing a phase shifting mask structure similar to the above, although the following examples are less advantageous than the first, second and third embodiments since the plotting step needs to be executed twice.

In a fourth embodiment, as illustrated in Figure 10(a), a light shielding film 10' is formed on a transparent substrate of quartz or the like by evaporation of a light shielding material such as chromium, and a resist film 2' is formed thereon. Subsequently, an opening 21 of a size corresponding to a desired transparent region 20 (see Figure 10(c)) is formed in the resist film 2' by normal photolithography thereby obtaining a resist pattern 2 (Figure 10(b)).

The light shielding film 10' is partially removed by etching or the like while being masked with the resist pattern 2, and then the remaining resist pattern is removed to produce a structure as shown in Figure 10(c) which includes a light shielding region 10 and a transparent region 20.

Thereafter, a further resist 3' is formed over the entire surface as illustrated in Figure 10(d).

In the next step, an opening 31 of a size corresponding to a desired light transmitting segment 12 is formed in the resist 3' to provide a resist pattern 3 as illustrated in Figure 10(e).

The substrate 1 is partially etched while being masked by the resist pattern 3 so that, as illustrated in Figure 10(f), the central portion of the transparent region 20 becomes reduced in thickness. This central portion serves as a light transmitting segment 12, and its two sides serve as the phase shifting segments 11a, 11b.

Thus, in this embodiment, the phases of the transmitted light beams are rendered mutually different by partially changing the thickness of the substrate 1, thereby forming the light transmitting segment 12 and the phase shifting segments 11a, 11b.

In a fifth embodiment shown in Figures 11(d) to 11(f), the steps up to and including forming the light shielding region 10 and the transparent region 20 are the same as those in the fourth embodiment as shown in Figures 10(a) to 10(c). Thereafter, as illustrated in Figure 11(d), a layer 4' having a phase shifting effect is formed over the surface, and a resist film 5' is formed thereon. An opening 51 corresponding to a light transmitting region 12 (Figure 11(f)) is then formed in the resist film 5' by photolithography to produce a resist pattern 5 as shown in Figure 11(e). The material 4' having a phase shifting effect is patterned by etching or the like while being masked with the resist pattern

5. Subsequently, the resist pattern 5 is removed to produce the structure of Figure 11(f). In this structure, a projection 4 of the phase shifting material 4' is formed in a thickness d on each side of the transparent region 20 to serve as a phase shifting mask. The portions where such projection 4 is present on the transparent region 20 are used as phase shifting segments 11a, 11b, while any other portion of the transparent region 20 is used as a light transmitting segment 12.

The thickness d of the projection 4 is selected so as to be optimal for attaining a desired phase shift. For example, the thickness d determined according to the aforementioned equation is selected to cause a phase shift of 180°.

In this embodiment, the phase shifting segments 11a, 11b are composed of a phase shifting film as described above. Materials suited for the film may include, in addition to silicon dioxide, organic materials such as polyimide resin or resist material, or inorganic materials such as silicon nitride. It is also possible to use any material that can be processed so as to finally become silicon dioxide by baking, such as SOG.

In a sixth embodiment, the early steps correspond to those of Figures 10(a) to 10(e) of the fourth embodiment, such that the structure of Figure 10(e) is obtained with a resist pattern 3 formed on a light shielding region 10. Subsequently, a material having a phase shifting effect is deposited as illustrated in Figure 12(f), whereby a projection 6 of the phase shifting material is formed in the portion of the transparent region 20 of the substrate 1 not covered with the resist pattern 3. Simultaneously, a film 61 of the phase shifting material is formed on the resist pattern 3 as well.

The resist pattern 3 is then removed such that, as illustrated in Figure 12(g), a phase shifting segment 11 composed of the projection 6 is formed at the centre of the transparent region 20, and light transmitting segments 12a, 12b are formed on both sides of the segment 11. In this stage, the film 61 of the phase shifting material deposited on the resist pattern 3 in the step of Figure 12(f) has already been removed together with the resist pattern 3.

In comparison with the fifth embodiment of Figures 11(d) to 11(f) in which the light transmitting segment 12 is formed at the centre of the transparent region 20, the sixth embodiment involves a process in reverse whereby the phase shifting segment 11 is formed at the centre of the transparent region 20, and its two sides are used as the light transmitting segments 12a, 12b.

The thickness d and the material of the projection to be used as a phase shifting segment can be the same as those in the fifth embodiment.

## Claims

1. A phase shifting mask comprising, on a substrate (1), a transparent region (20) which is transparent to exposure light and a light shielding region (10) for shielding the exposure light, said transparent region (20) having a light transmitting segment (12) for directly transmitting the exposure light therethrough and a phase shifting segment (11; 11a, 11b) for transmitting the exposure light therethrough with a phase difference from the light transmitted through said light transmitting segment (12),  
characterised in that said light shielding region (10) is formed adjacent at least said phase shifting segment (11; 11a, 11b) or said light transmitting segment (12), and said phase shifting segment (11; 11a, 11b) and said light transmitting segment (12) are formed adjacent each other.
2. A phase shifting mask according to claim 1, wherein said phase shifting segment is a recess (1a) formed in said substrate (1).
3. A phase shifting mask according to claim 1, wherein said phase shifting segment is a projection (42) formed on said substrate (1).
4. A phase shifting mask according to claim 3, wherein said projection (42) is composed of SiO<sub>2</sub>, polyimide resin, Si<sub>3</sub>N<sub>4</sub>, SOG or photoresist material.
5. A method of manufacturing a phase shifting mask, the method comprising the steps of :  
forming a light shielding layer (10') on a substrate (1);  
forming a photoresist (2') on said light shielding layer (10');  
patterning said photoresist (2') to form a resist pattern (2);  
forming an opening (10a) in said light shielding layer (10') by the use of said resist pattern (2) as a mask, thereby forming a light shielding pattern (10b);  
etching said substrate (1) anisotropically to form a phase shifting segment (1a);  
side etching said light shielding pattern (10b) to form a light shielding region (10); and  
removing said resist pattern (2).
6. A method of manufacturing a phase shifting mask, the method comprising the steps of :  
forming a light shielding layer (10') on a substrate (1);  
forming a photoresist (2') on said light shielding layer (10');  
patterning said photoresist (2') to form a resist pattern (2);  
forming an opening (10a) in said light shielding layer (10') by the use of said resist pattern (2) as a mask, thereby forming a light shielding pattern (10b);  
etching said substrate (1) anisotropically to form a phase shifting segment (1a);  
removing said resist pattern (2); and  
etching said light shielding pattern (10b) isotropically to form a light shielding region (10).
7. A method of manufacturing a phase shifting mask, the method comprising the steps of :  
forming a light shielding layer (10') on a substrate (1);  
forming a photoresist (2') on said light shielding layer (10');  
patterning said photoresist (2') to form a resist pattern (2);  
forming an opening (10a) in said light shielding layer (10') by the use of said resist pattern (2) as a mask, thereby forming a light shielding pattern (10b);  
side etching said light shielding pattern (10b) to form a light shielding region (10);  
depositing a phase shifting material in said opening (10a) by the use of said resist pattern (2) as a mask; and  
removing said resist pattern (2) together with phase shifting material (41) thereon to form a phase shifting segment (42) in said opening (10a).
8. A method of manufacturing a phase shifting mask, the method comprising the steps of :  
forming a light shielding layer (10') on a substrate (1);  
forming a photoresist (2') on said light shielding layer (10');  
patterning said photoresist (2') to form a first resist pattern (2);  
forming an opening (20) in said light shielding layer (10') by the use of said first resist pattern (2) as a mask, thereby forming a light shielding pattern (10);  
removing said first resist pattern (2);  
forming a photoresist (3') on said light shielding pattern (10) and said opening (20);  
removing said photoresist (3') partially from said opening (20) thereby forming a second resist pattern (3);  
anisotropically etching said substrate (1) in a partial area (31) of said opening (20) thereby forming a phase shifting region (11a, 11b); and  
removing said second resist pattern (3).
9. A method of manufacturing a phase shifting

mask, the method comprising the steps of :

forming a light shielding layer (10') on a substrate (1) ;

forming a photoresist (2') on said light shielding layer (10') ; 5

patterning said photoresist (2') to form a first resist pattern (2) ;

forming an opening (20) in said light shielding layer (10') by the use of said first resist pattern (2) as a mask, thereby forming a light shielding pattern (10) ; 10

removing said first resist pattern (2) ;

forming a layer (4') of a phase shifting material on said light shielding pattern (10) and said opening (20) ; 15

forming a photoresist (5') on said layer (4') of the phase shifting material ;

removing said photoresist (5') in such a manner as to leave a second opening (51) which is positioned over and is narrower than the first-mentioned opening (20), thereby forming a second resist pattern (5) ; 20

anisotropically etching said layer (4') of the phase shifting material by the use of said second resist pattern (5) as a mask, thereby forming a phase shifting region (4) ; and 25

removing said second resist pattern (5).

10. A method of manufacturing a phase shifting mask, the method comprising the steps of : 30

forming a light shielding layer (10') on a substrate (1) ;

forming a photoresist (2') on said light shielding layer (10') ;

patterning said photoresist (2') to form a first resist pattern (2) ; 35

forming an opening (20) in said light shielding layer (10') by the use of said first resist pattern (2) as a mask, thereby forming a light shielding pattern (10) ; 40

removing said first resist pattern (2) ;

forming a photoresist (3') on said light shielding pattern (10) and said opening (20) ;

removing said photoresist (3') partially from said opening (20) thereby forming a second resist pattern (3) ; 45

depositing a phase shifting material in said opening (20) partially by the use of said second resist pattern (3) as a mask ; and

removing said second resist pattern (3) together with said phase shifting material (61) thereon to leave a phase shifting segment (6) in a partial area of said opening (20). 50

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FIG. 1(b)

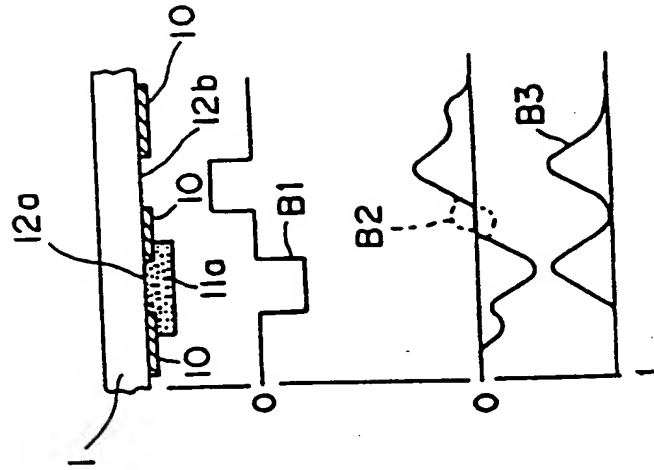


FIG. 1(a)

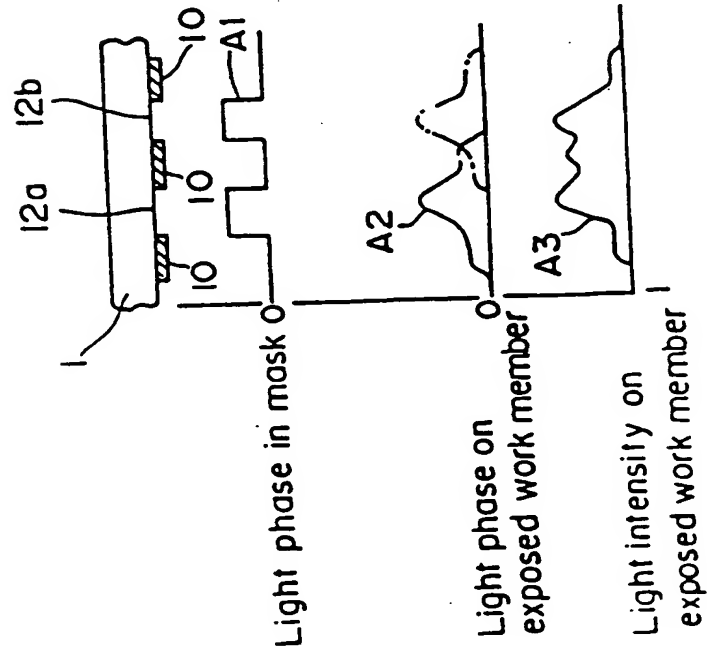


FIG. 2(a)

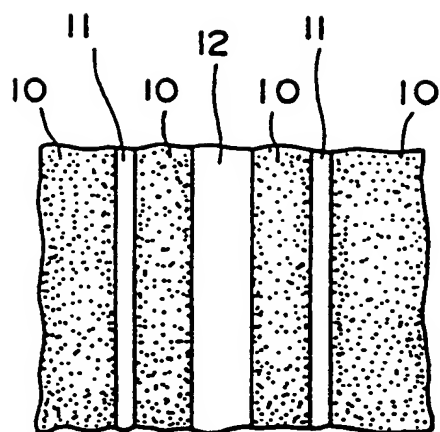


FIG. 2(b)

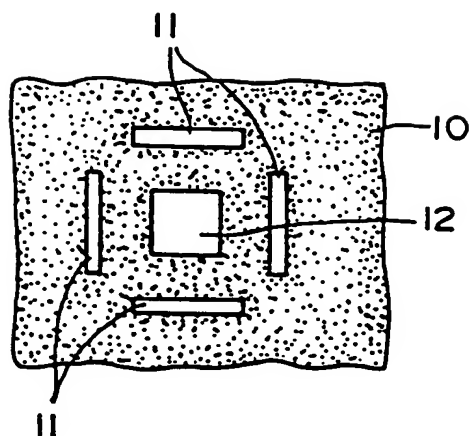


FIG. 3

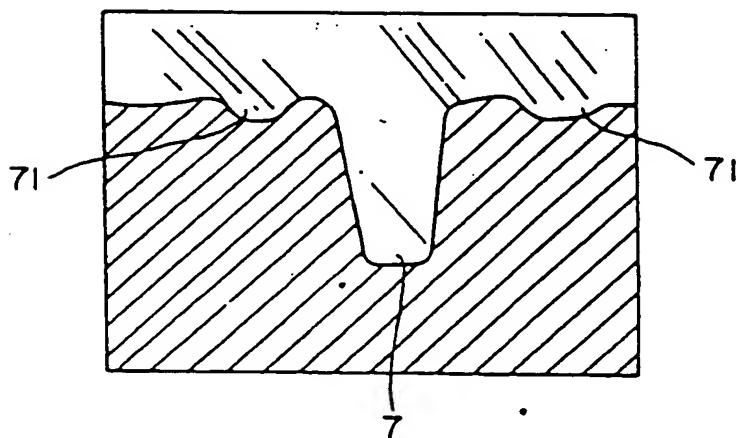


FIG. 4(a)

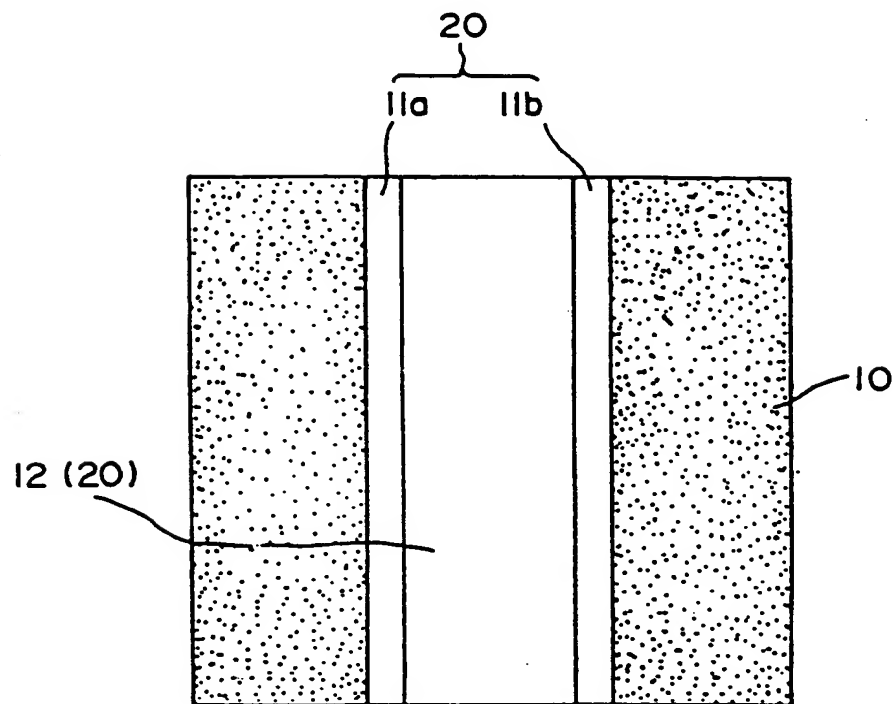


FIG. 4(b)

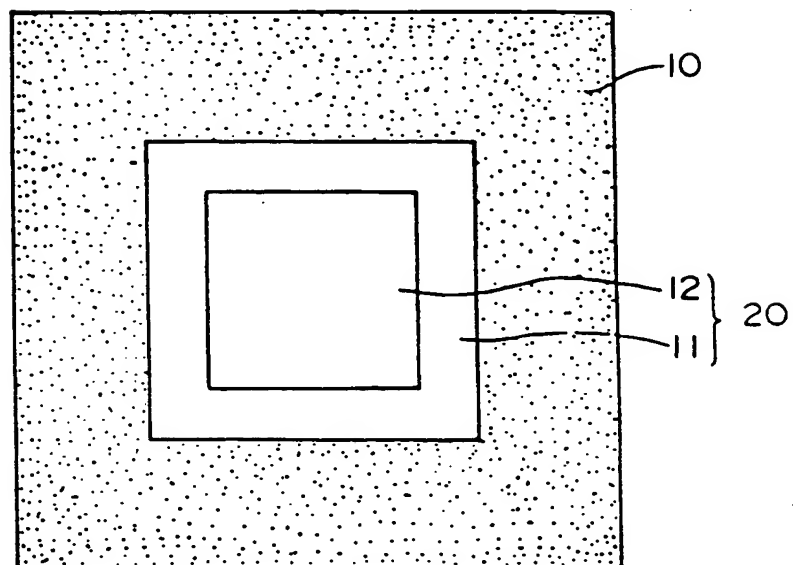


FIG. 5(a)

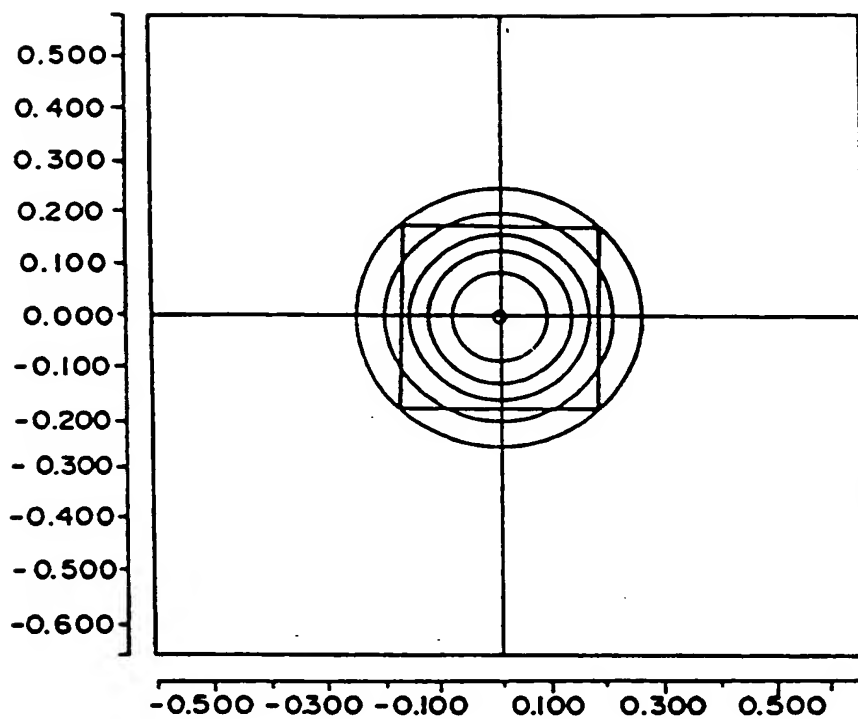


FIG. 5(c)

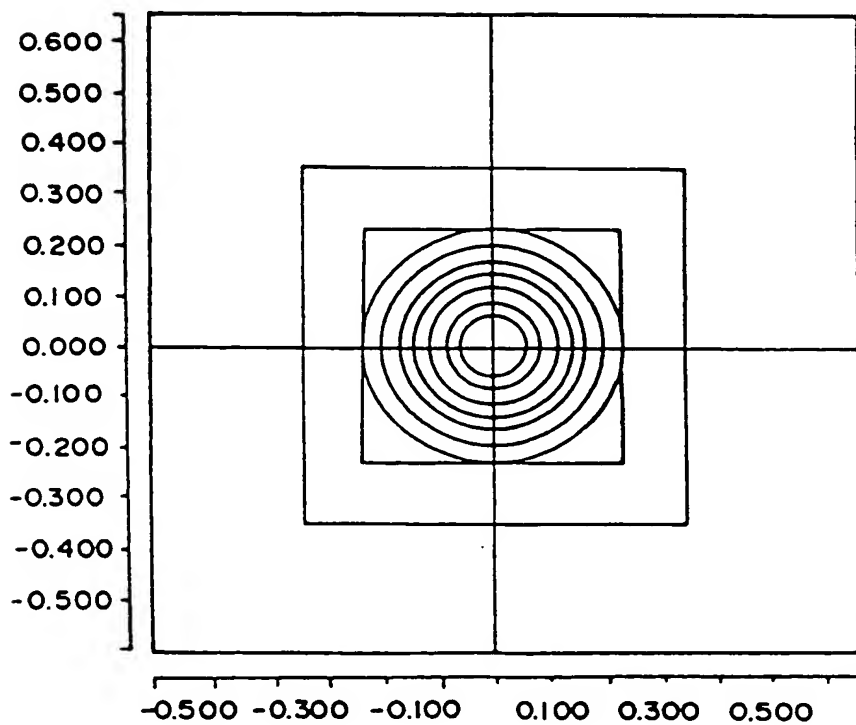


FIG. 5(b)

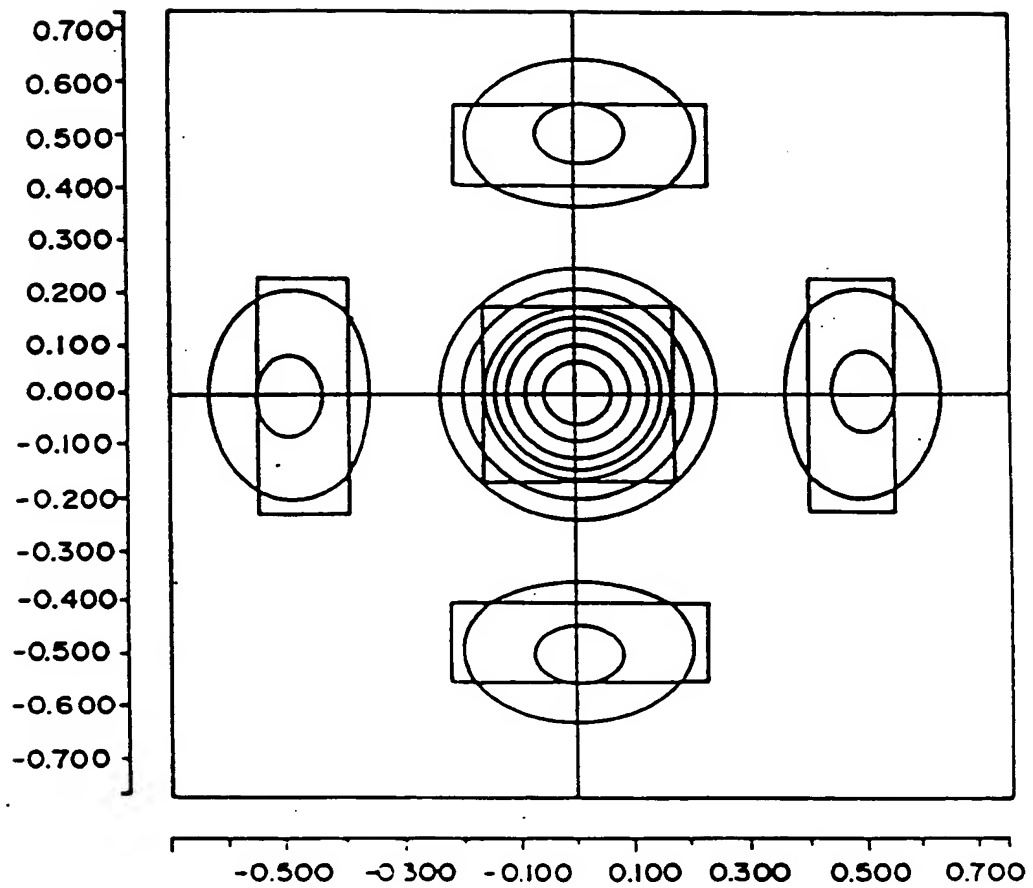


FIG. 6(a)

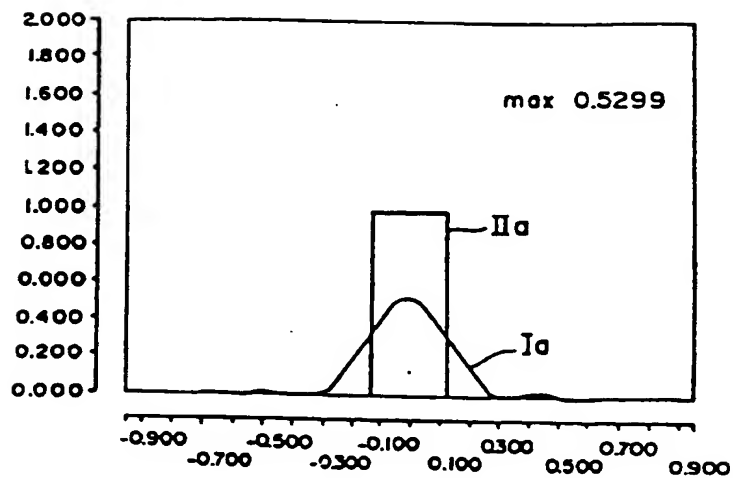


FIG. 6(b)

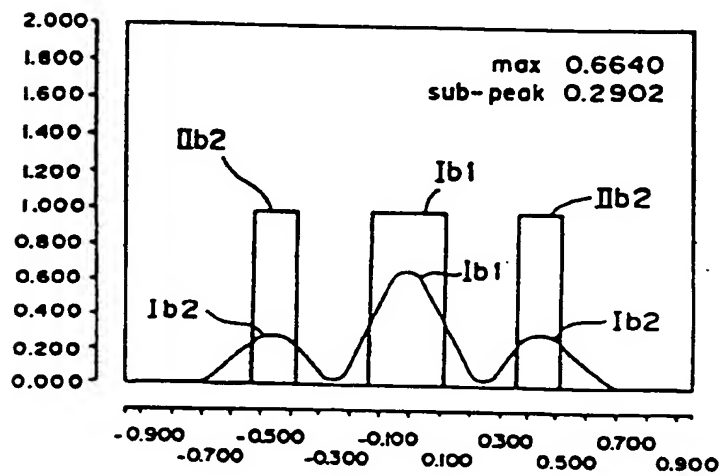
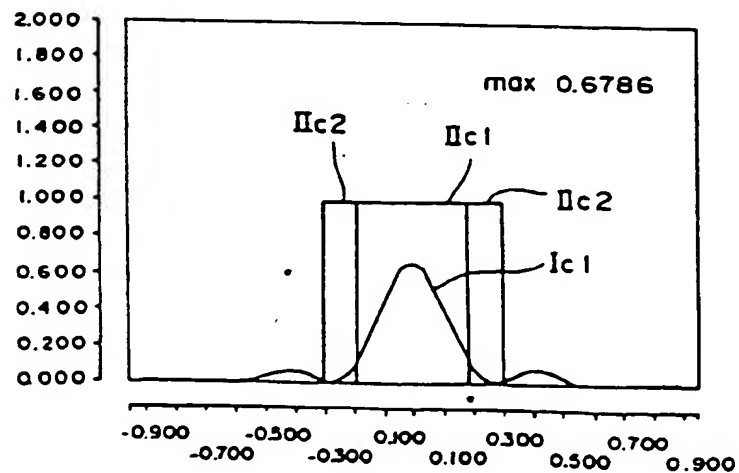


FIG. 6(c)



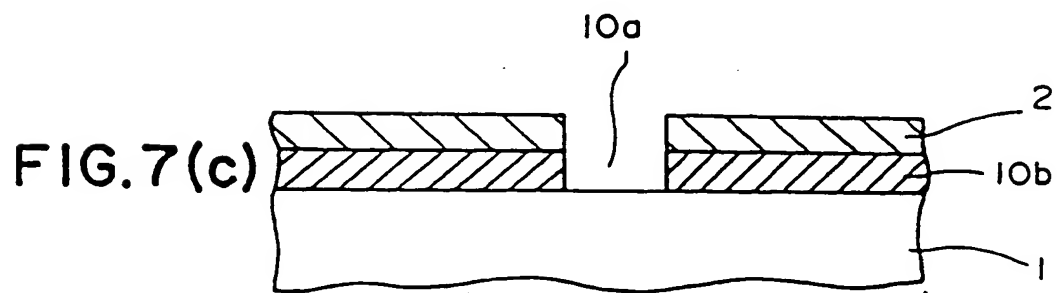
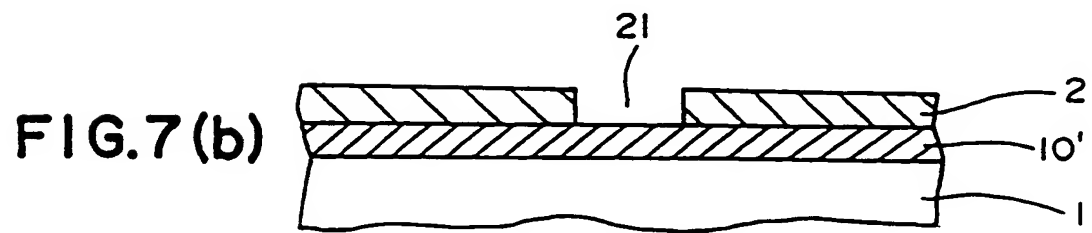
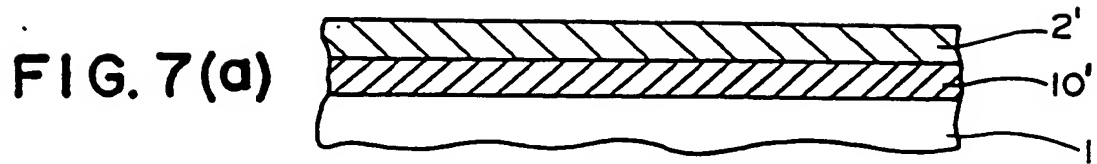


FIG. 7(d)

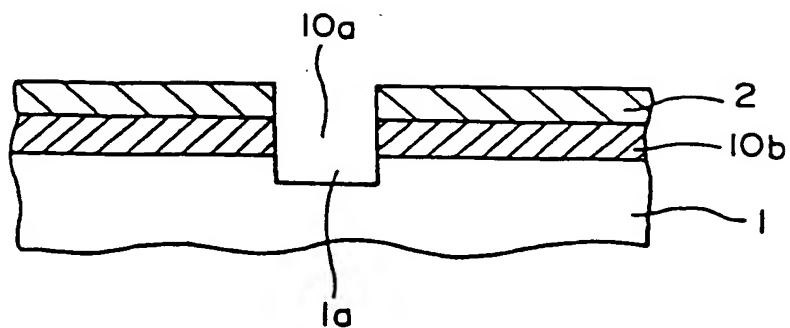


FIG. 7(e)

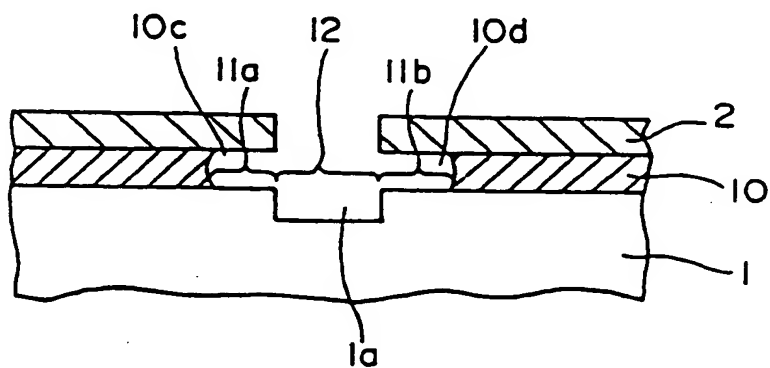


FIG. 7(f)

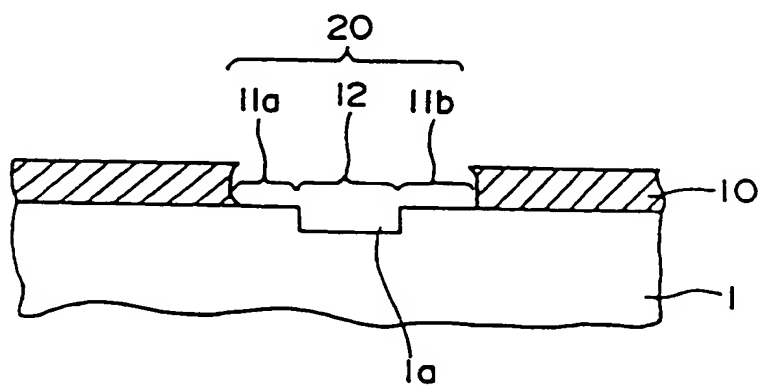


FIG. 8(a)

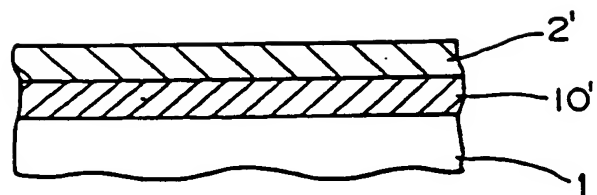


FIG. 8(b)

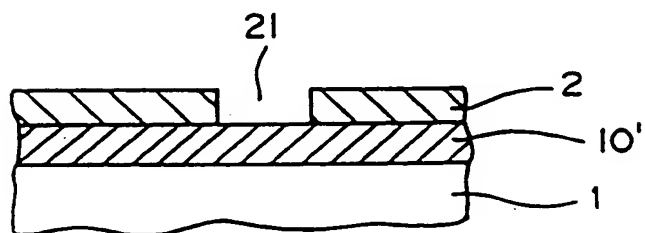


FIG. 8(c)

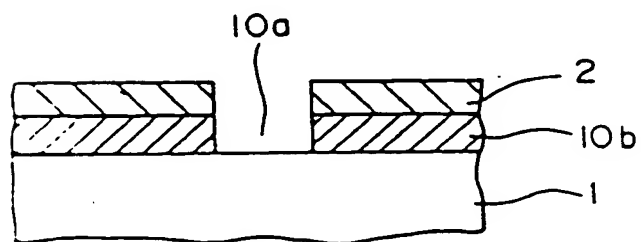


FIG. 8(d)

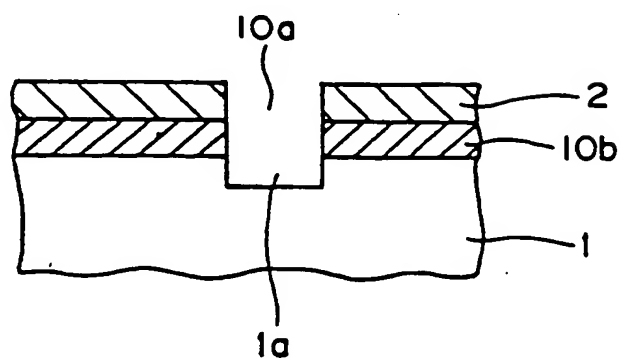


FIG. 8(e)

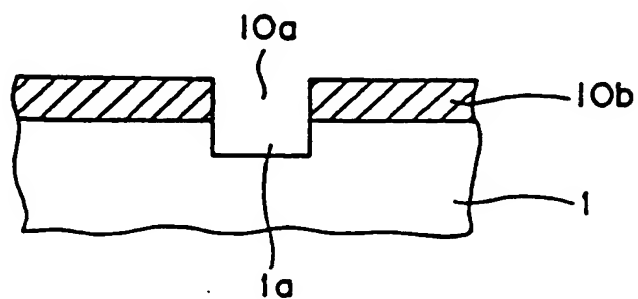


FIG. 8(f)

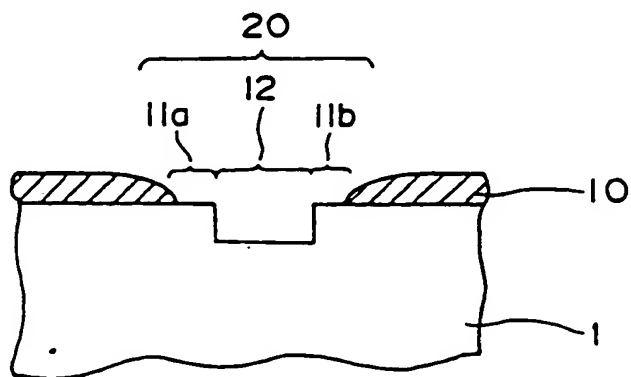


FIG. 9(d)

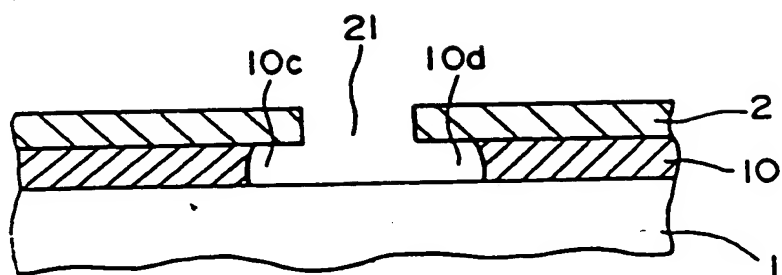


FIG. 9(e)

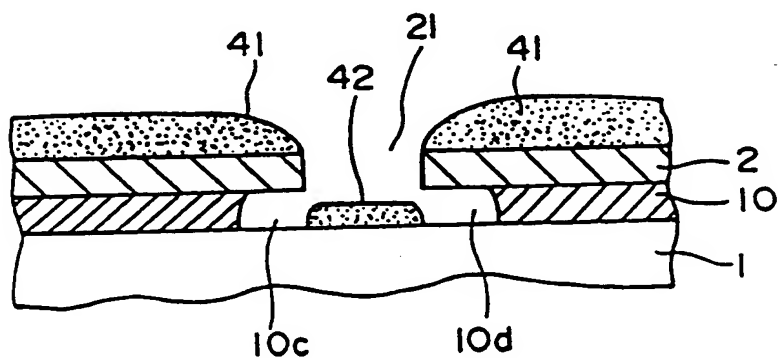


FIG. 9(f)

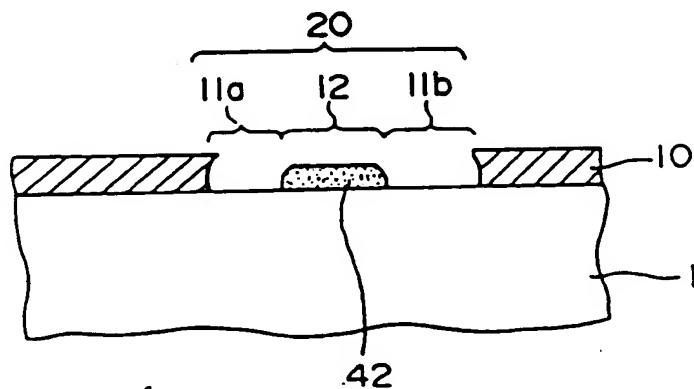


FIG. 10(a)

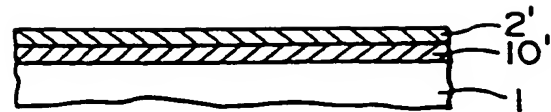


FIG. 10(b)

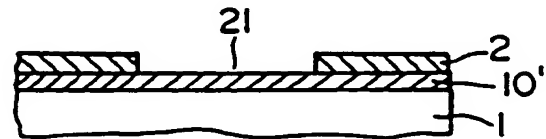


FIG. 10(c)

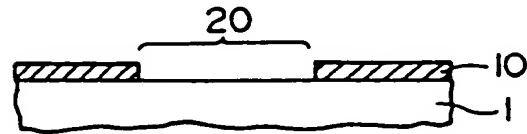


FIG. 10(d)

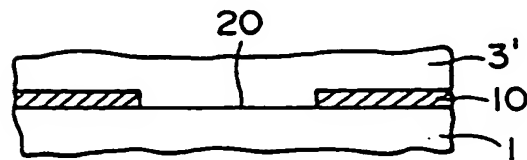


FIG. 10(e)

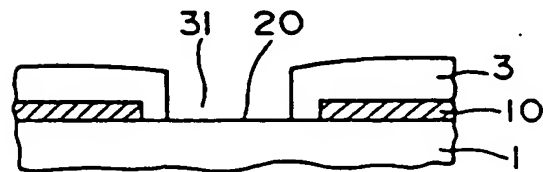


FIG. 10(f)

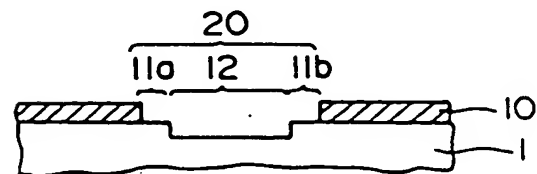


FIG. II (d)

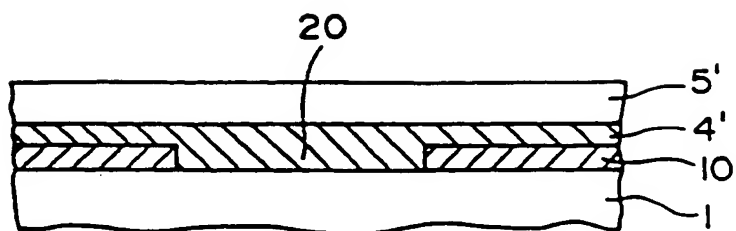


FIG. II (e)

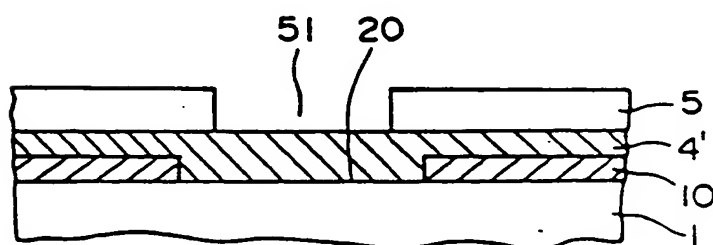


FIG. II (f)

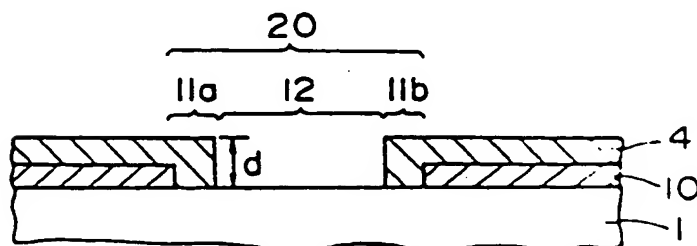


FIG. 12(f)

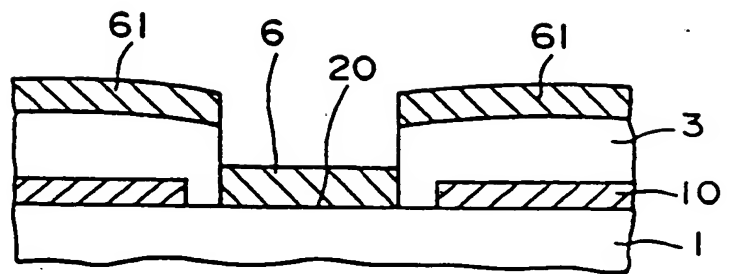


FIG. 12(g)

